ORIGINAL ARTICLE

Daily, seasonal, and annual variability of temperature in streams inhabited by the endemic San Pedro Martir trout (*Oncorhynchus mykiss nelsoni*), in Baja California, Mexico, and the predicted temperature for the years 2025 and 2050

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ABSTRACT

The present study measured the daily, seasonal, and annual variability of the water temperature of streams in which the endemic rainbow trout, *Oncorhynchus mykiss nelsoni*, is distributed on the western slope of the Sierra San Pedro Mártir, Baja California, Mexico, between 1996 and 2019. The seasonal thermal interval and daily duration of summer temperatures above the thermal threshold for this trout subspecies (≥28°C) were determined in streams at different elevations (553, 1,220, and 2,080 m asl, or meters above sea level). Temperatures 28°C were recorded at the study site on the stream with the lowest elevation (San Antonio de Murillos Creek) over an accumulated 365 h between June and September 2014, with the maximum temperature recorded there, 30.66 °C, making it the site most vulnerable to global warming. At the San Antonio de Murillos Creek site, the average water temperature predicted by three models (GFDL R30, HadCM3, and Mote) for the year 2025 would be a non-lethal temperature, <28°C, for trout at a minimum elevation of 491-511 masl, while this was predicted to be 545-701 masl for the year 2050. Predicted hourly water temperatures of 28°C (non-lethal) may occur at minimum elevations of 868-898 masl in 2025 and at 908-1028 masl in 2050, reducing a 21-23% and 23-31% its current altitudinal distribution range, respectively, thus avoiding its presence at the type locality (San Antonio de Murillos).

INTRODUCTION

Global warming affects the distribution of species and modifies their habitat by increasing or decreasing their range of distribution (Parmesan and Yohe, 2003; Root *et al.*, 2003). The Intergovernmental Panel on Climate Change (IPCC) (2007) states that the global warming evident in the recent instrumental record will continue and even accelerate. Global temperatures have increased by an average of approximately 0.85°C since the end of the 19th century, and extreme climatic events, including storms, floods, droughts, and heatwaves, are increasing in frequency (Christensen and Christensen, 2003; Stocker *et al.*, 2013).

Warmer air temperatures (Abatzoglou and Redmond, 2007; IPCC, 2007) cause an increase in the variability of rainfall (Hamlet *et al.*, 2007) and the frequency of forest fires (Westerling *et al.*, 2006; Morgan *et al.*, 2008), as well as decreased snow cover and dissolved oxygen levels of water (Mote *et al.*, 2005). The events before mentioned are responsible of the warming of river and stream waters (Petersen and Kitchell, 2001; Morrison *et al.*, 2002; Bartholow, 2005), the alteration of hydrological currents (Barnett *et al.*, 2008; Luce and Holden, 2009), and the increased disturbance of river beds due to flooding, landslides, and debris flow (Istanbulluoglu *et al.*, 2004; Hamlet and Lettenmaier, 2007).

Temperature largely governs the distribution and abundance of species on a spatial and temporal scale (Rieman *et al.*, 2007; Wenger *et al.*, 2011). As global warming progresses and the planet's temperatures rise, aquatic communities in lotic systems such as streams and rivers will have to adapt to new thermally-modified habitats. However, these communities can undergo adaptation difficulties in places where river networks are fragmented due to the development of water infrastructure that modify

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the quality and quantity of flow downstream (Daufresne and Boet, 2007; Heino *et al.*, 2009). The members of the family Salmonidae are strictly dependent on cold waters with high levels of oxygenation and flow (Leppi *et al.*, 2010), so changes in maximum water temperatures of only a few degrees due to global warming can have significant effects on the occurrence and distribution of trout in streams (Magnuson *et al.*, 1997; Lyons *et al.*, 2009; Rieman and Isaak, 2010).

It is well-known that water temperatures >25°C result to be lethal for most rainbow trout (Bidgood and Berst, 1969), including the southern rainbow trout subspecies (Matthews, 2010). The streams of southern California, USA, register temperatures as high as 28°C in the summer, with rainbow trout preferring the habitat of cold deep pools to the warmer conditions in streams (Matthews and Berg, 1997). One possible explanation for the survival of this trout in high temperatures is the refuge offered by the thermal micro-shelters created by groundwater inlets or stratified ponds (Matthews and Berg, 1997). However, the extent of the refuge habitat offered by these sites is uncertain due to the likely increase in water temperature in the coming decades.

Various factors influence the habitat suitability of salmonid fishes. Crozier and Zabel (2006) found a low survival of salmonids in warm wide streams with low flow rates, while a high survival in colder narrower streams with flow rates. In warmer, wider streams, the individual's developmental process deteriorates as the temperature rises above the optimal level, while the risk of predation increases (Marine and Cech, 2004) and the availability of prey decreases (Bisson and Davis, 1976).

The endemic trout *O. m. nelsoni* (Evermann, 1908) inhabits the western slope of the Sierra San Pedro Mártir (SSPM), northwestern Baja California, Mexico and is considered as the southernmost subspecies of the rainbow complex in North America (Behnke, 2002). This trout is in the category of special protection (Ruiz-Campos and Pister, 1995; Official Mexican Standard, 2010; Ruiz-Campos *et al.*, 2014) and face a series of threats related to the alteration of their habitats due to the impact of cattle farming and the reduction of stream flow as result of pumping or channeling water for agricultural irrigation in the adjacent coastal region (Ruiz-Campos, 2017). Therefore, there is the imminent threat of reduction in its distribution by global warming's predicted increased water temperature. The trout would only survive in higher elevations conducive to the formation of thermal micro-shelters (Rieman and Isaak, 2010; Ruiz-Campos, 2017).

The future effects of the climate on the distribution of *O. m. nelsoni* demand the recording and assessment of water temperature variations in their habitats on a daily, monthly, and annual basis in the SSPM.

The aim of this study was to measure the daily, seasonal, and annual variability of the water temperature in streams of the Sierra San Pedro Mártir, Baja California, Mexico (period of 1996 to 2019), inhabited by the endemic rainbow trout, *Oncorhynchus mykiss nelsoni*. These data determined the seasonal thermal interval and daily duration of summer temperatures above the thermal threshold for this trout subspecies (≥28°C) at different elevations.

Study area

The present study was conducted in three-second order streams on the western slope of the SSPM, two located in the Santo Domingo river basin (La Grulla Creek and San Antonio de Murillos Creek) and one in the San Rafael river basin (San Rafael Creek), at an altitude ranging from 553 to 2,080 m asl (Fig. 1). The study sites were selected based on the known presence of the San Pedro Martir trout (Ruiz-Campos, 2017), as monitored for population density and status from 1987 to the present day.

The regional climate is subhumid with an average annual temperature and precipitation of 7 °C and 400 mm, respectively (García and Mosiño, 1968; Álvarez and Maisterrena, 1977; Álvarez, 1985). The Santo Domingo river basin is the largest in the SSPM (Ruiz-Campos, 1991), with its six tributaries (La Grulla, El Potrero, Valladares, Santa Cruz, La Zanja, and San Antonio de Murillos), while the tributaries of the San Rafael river basin are the La Fresa, Vallecitos, and Agua Zarca creeks (Ruiz-Campos, 2017). These first and second order streams are perennial, with maximum flow presenting during the winter rainy season (Ruiz-Campos, 2017), and mainly shallow (<0.5 m deep), although some of their pools can be as deep as 1.5 m (Ruiz-Campos, 1991). The environmental temperature is highly variable, with minimum and maximum values of -12°C in winter and 35°C in summer, respectively (Reyes-Coca and García-López, 1991). The arboreal riparian vegetation is dominated by *Populus fremotii*, *Platanus racemosa* and *Salix lasiolepis,* bushy species by *Baccharis salicifolia, and* aquatic macrophytes by *Potamogeton natans* and *Ceratophyllum demersum* (Ruiz-Campos, 2017).

METHODS

The water temperatures were recorded in those sites where the endemic rainbow trout *O. mykiss nelsoni* has been previously reported (Ruiz-Campos and Pister, 1995; Ruiz-Campos *et al.*, 2014), at three different elevations in the SSPM (553 m asl at San Antonio de Murillos Creek, 1,220 m asl at San Rafael Creek, and 2,080 m asl at La Grulla Creek) between 1996 and 2019. The sites of La Grulla and San Antonio de Murillos represent the altitudinal range of distribution of this subspecies (Ruiz-Campos, 2017). Two to three submersible thermometers

(HOBO Brand Pendant, Model UA-002-08, ± 0.01°C) were used at each study site, where each thermometer was placed on the stream bed, mainly in a shaded pool at a depth > 0.4 m, and then held in place with steel wire affixed to a tree trunk. Thermographs were then used to record the water temperature at 1 h-intervals for at least one year, at the end of which, each thermograph was removed and immediately replaced with another thermograph pre-programed to continue recording the water temperature.

At the La Grulla and the San Rafael sites, the water temperature was measured in two periods; 1999-2000 and 2015-2019 at La Grulla, and 1996-1997 and 2014-2015 at San Rafael. At the San Antonio de Murillos site, temperature was measured in only one period, 2014-2015.

The data was retrieved from each thermometer via the ®HOBOware software and then transferred to an ®MS Excel 2016 file for analysis and interpretation on a daily, monthly, and annual basis, establishing the minimum, maximum, and average values for the three sites.

With water temperatures ≥28°C known to be lethal for southern rainbow trout populations in North America (Kammerer and Heppell, 2013a; Matthews and Berg, 1997). The present study the total number of hours in which temperatures equal to, or was above 28°C, was calculated.

At the La Grulla site, one way-ANOVA tests were used to compare the daily average temperature values among the three years (1999, 2016 and 2017), while, at the San Rafael site, a Student's *t*-test was used to compare the average daily values for the two years in which measurements were taken (1996 and 2014) (Sokal and Rohfl, 1981). At the San Antonio de Murillos site, no statistical comparison was performed because only 1 year of measurements was recorded. The average daily water temperatures at each site were statistically compared for each summer in which the study was conducted.

Three climate prediction models based on water temperature records were used to predict the temperatures at the three study sites: the GFDL R30 model from the Geophysical Fluid Dynamics Laboratory (Delworth *et al.*,

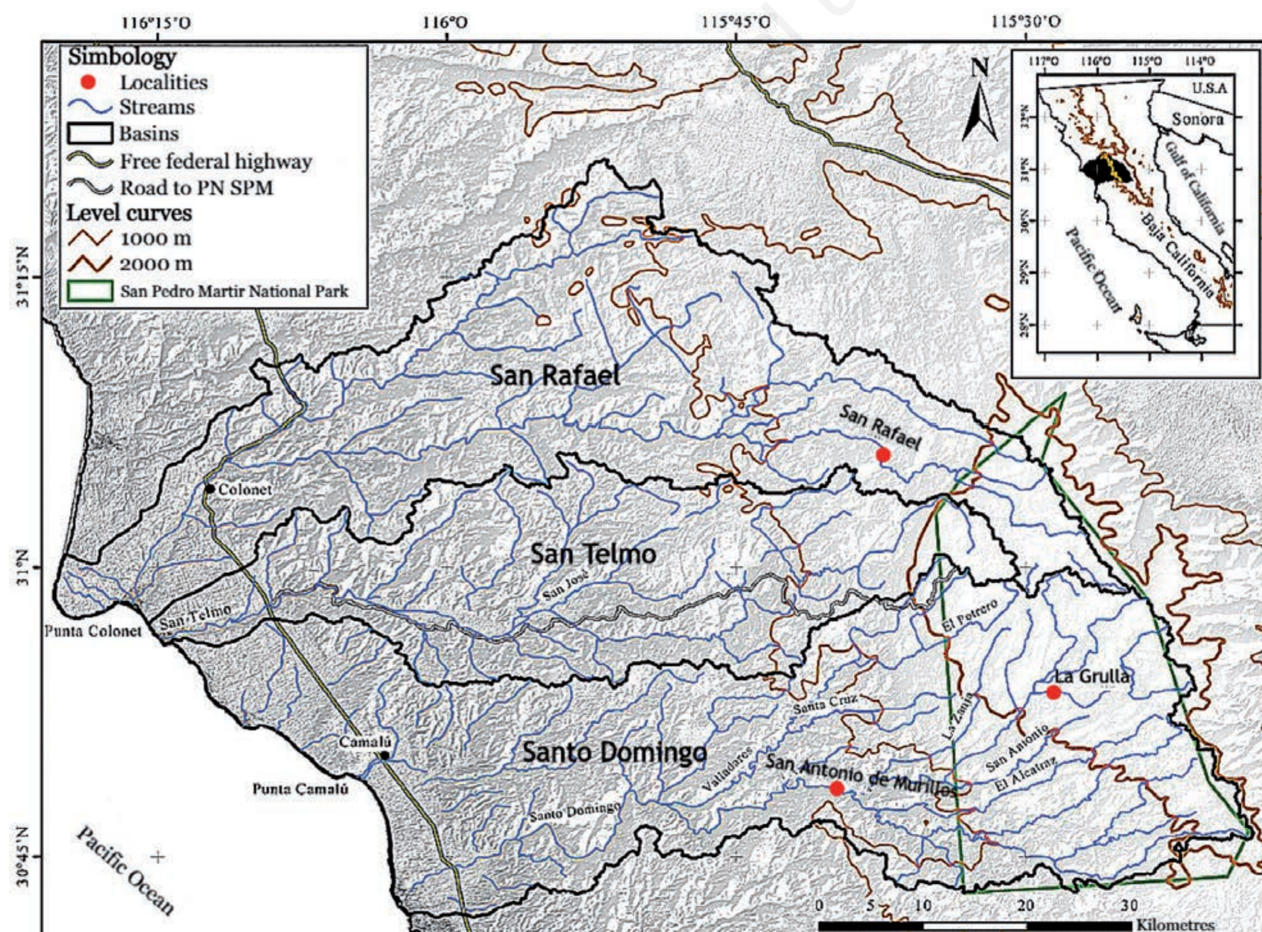

Fig. 1. Surface hydrology of the western slope of the SSPM, Baja California, Mexico, showing the boundaries of the basins and study sites (La Grulla, San Rafael and San Antonio de Murillos creeks).

2002); the HadCM3 model from the Hadley Center, which was also used by the United Nations Framework Convention for Climate Change (Pope *et al.*, 2000; Conde *et al.*, 2011); and, the Mote model (Mote *et al.*, 2003), which is based on the analysis of eight climate models of the global oceanic atmosphere available through the IPCC Data Distribution Center. The three models were used to project temperatures for the years 2025 and 2050, based on the A2 emissions scenario (Nakicenovic *et al.*, 2000), and linked to the water temperature of the streams in order to determine trends and identify the times and places in which temperatures ≥28°C were present.

The first prediction, generated using the GFDL R30 model, was a temperature increase of 0.6°C for the year 2025 and 0.95°C for the year 2050, while the second, based on the HadCM3 model, produced a temperature increase of 0.45°C and 0.85°C for the years 2025 and 2050, respectively. Finally, the Mote model predicted a global increase of 0.75°C for the year 2025 and 2°C for the year 2050. The last complete annual temperature records were used for the predictive modeling, corresponding to 2016 for La Grulla Creek and 2014 and 2015 for San Rafael and San Antonio de Murillos creeks.

The elevation (m asl) in the Santo Domingo river basin (San Antonio de Murillos and La Grulla creeks), where the water temperatures are predicted to remain below the lethal temperature for this trout subspecies by the years 2025 and 2050, was estimated based on the average values (both daily and hourly) generated by the three models. The predicted altitude was calculated as $y = n + m * x$, where: y = calculated altitude; x = average water temperature; and, n and m are the intercept and slope, respectively, of the linear regression. Both constants, n and m, were assessed using a 2 x 2 system of linear equations (Lehmann, 1986).

RESULTS

Daily, monthly, and annual temperature variations

La Grulla Creek

The water temperature in 1-hour intervals each day show a similar distribution pattern for each year (Fig. 2A). The lowest temperature (0.12°C) was recorded on 23 January 2017, at 08:00:07 h, while the highest temperature (17°C) was recorded on 8 September 2015, at 23:00:07 h. The average temperature between 2015 and 2019 was 10.36±4.09°C. No temperatures ≥28°C were recorded in this period.

The comparison of average daily water temperatures between two periods (June 1999-May 2000 and August 2015-April 2019) is shown in Fig. 2B. The lowest average daily temperature in the first period (5.56°C) was calculated on 8 March 2000 and the highest (14.9°C) on 13 July 1999, while the average temperature was 11.91±1.73°C. The lowest average daily water temperature in the second period (0.52°C) was calculated on 21 January 2017 and the highest (16.7°C) on 31 July 2016, while the average temperature during this period was 10.36±4°C. A comparison of the temperatures calculated in the two periods (Fig. 2B) shows a greater range of variation between the lowest and highest temperatures in recent years, namely a greater difference in the average daily temperatures calculated for the different seasons of the year.

Statistical analysis was performed on the summer temperature records, based on the average daily values obtained at the study sites. At the La Grulla site, the average daily temperature was significantly different depending on the year (1999: mean = 13.77±0.44°C; 2016: mean = 15.39±0.96°C; and 2017: mean = 15.34±0.53°C; one-way ANOVA, F=162.03, $P<0.001$).

San Rafael Creek

The water temperature was recorded at 1 h intervals at the San Rafael site (1,220 m asl) from February 2014 to February 2015 (Fig. 3A), with the lowest temperature (3.05°C) recorded on 1 January 2015 and the highest (27.17°C) on 8 June 2014. The average temperature during this period was 14.58±4.9°C, while no temperatures ≥28°C were detected.

The comparison of average daily water temperatures between two periods (May 1996-May 1997 and February 2014-February 2015) is shown in figure 3B. The lowest average daily temperature in the first period (3.72°C) was calculated on 7 January 1997 and the highest (24.04°C) was on 31 July 1996, while the average temperature was 14.704±5.69°C. Moreover, the lowest average daily temperature in the second period (4.01°C) was calculated on 2 January 2015 and the highest (23.17°C) was on 7 July 2014, while the average temperature was 14.58±4.75°C.

The average temperature calculated during the summer at the San Rafael site was significantly different depending on the year (1996: mean= 21.35±2.03°C and 2014: mean= 20.35±1.67 °C; Student's t-test, t = 4.46, $P<0.001$).

San Antonio de Murillos Creek

The temperature values recorded at 1 h intervals at this site (553 m asl) from May 2014 to April 2015 are displayed in Fig. 4A. The lowest temperature value (5.19°C) was recorded on 2 January 2015, while the highest (30.66°C) was recorded on 15 August 2014. The average temperature during this period was 19.31±5.73 °C, with a high frequency of days with a temperature ≥28°C observed between 1 June 2014 and 26 September 2014, giving an accumulated time of 365 h. This was the only site at which the presence of trout coincided with daily records of high temperatures (≥28°C), which is explained by its low elevation.

Fig. 4B shows the average daily water temperature during from May 2014 to April 2015, with the lowest average daily value (6.91°C) calculated on 2 January 2015 and the highest average daily value (27.09 C) calculated on 17 August 2014. The average temperature for this entire period was 19.32±5.41°C.

Water temperature scenarios at the stream sites

The models applied were based on the water temperatures recorded at 1-hour intervals at the three sites between 2014 and 2016 and were used to determine the amplitude, time (in hours), and the sites with temperatures ≥28°C, which are lethal for the rainbow trout subspecies of interest.

At the La Grulla site, no temperature values higher than ≥28°C were predicted for the years 2025 and 2050 by the three global warming models, based on the 1-hour temperature recordings (Fig. 5A).

At the San Rafael site, no temperature values ≥28°C were predicted for the year 2025 (Fig. 5B), while for the year 2050, the three models predicted values above this threshold. The model (Mote 2050) using an increase of 2°C predicted the highest number of extreme events, predicting a total of 53 hours of temperatures ≥28°C between

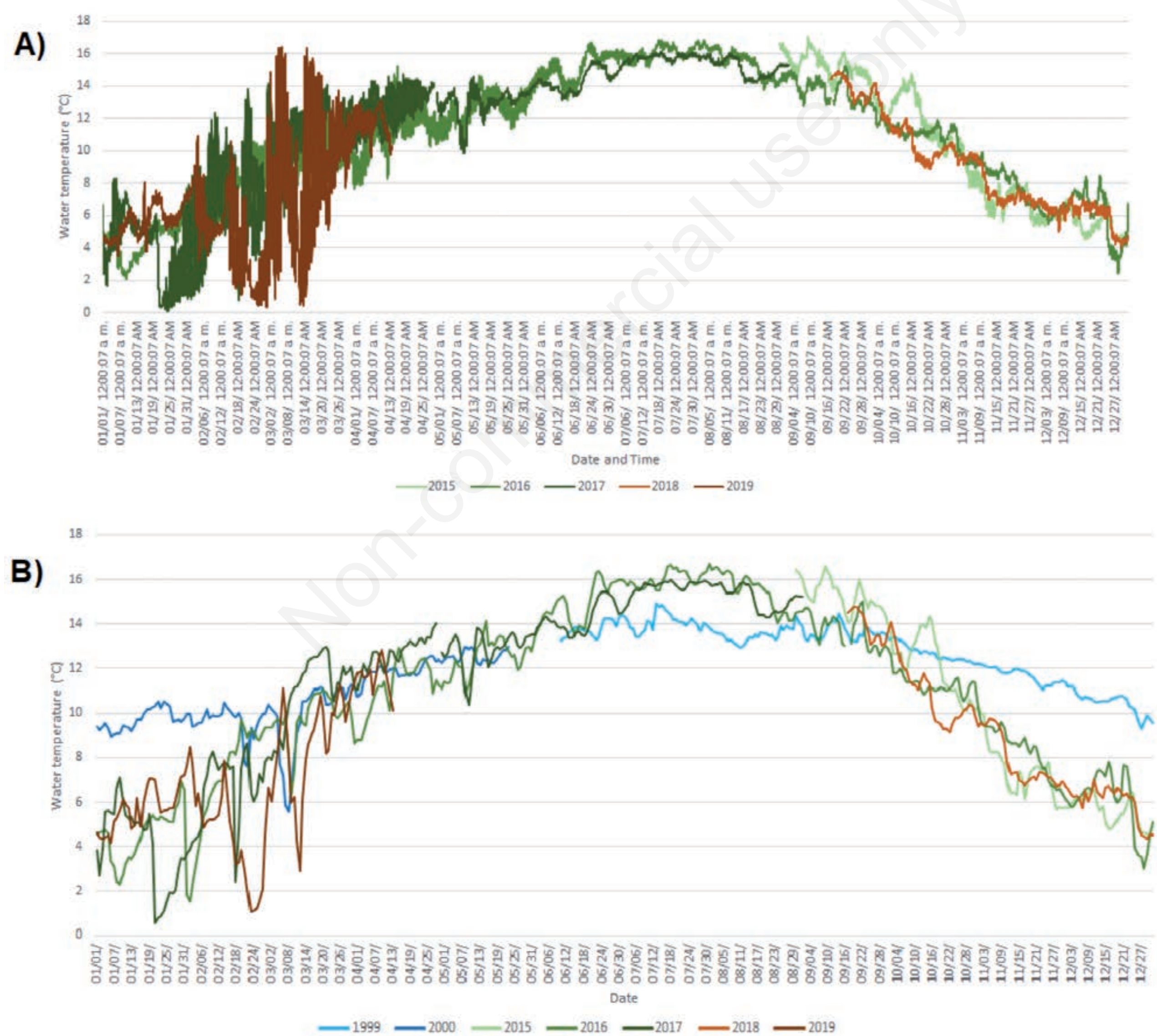

Fig. 2. A) Water temperature recorded with a dual meter at 1-hour intervals, from August 2014 to April 2019. B) Average daily temperature from June 1999 to May 2000 and August 2015 to April 2019, at an altitude of 2,080 m asl, in La Grulla Creek, SSPM, Baja California.

June 29 and August 15, 2050. In the model (HadCM3 2050), using an increase of 0.85°C), predicted the least number of extreme termal events (≥28°C) with a total of three hours between June 30 and August 8, 2050 (Tab. 1).

Fig. 6 shows the water temperature at the San Rafael site on the same date in summer (28 July) for the years 1993 and 2014 as well as the temperature predicted for the same date in 2050 by the third model (Mote 2050) (+2°C). This date (28 July) was chosen based on water temperature records for 24 July 1993, which were compared with recent (2014) and predicted data (2050) for this date. A trend of increasing water temperatures was found at any time on the same date for the three different years, reaching, by the year 2050, temperatures (≥28°C) that are lethal for the survival of rainbow trout subspecies.

Based on the three models of predictions for the San Antonio de Murillos site, a significant and lethal increase in water temperature (≥28°C) is expected to occur in the habitat for the endemic trout in the years 2025 and 2050 (Fig. 5C). For the year 2025, the model (Mote 2025) (increase of 0.75° C) predicted the highest frequency of extreme temperatures (≥28°C) with a total of 610 h between June 29 and September 26 (Tab. 1); while the model (HadCM3 2025) with an increase of 0.45°C predicted a lesser number of hours (493) with lethal temperatures between May 31 and June 26 (Tab. 1).

For the year 2050, at this same site, the Mote 2050 model (increase of 2°C) predicted the highest number of

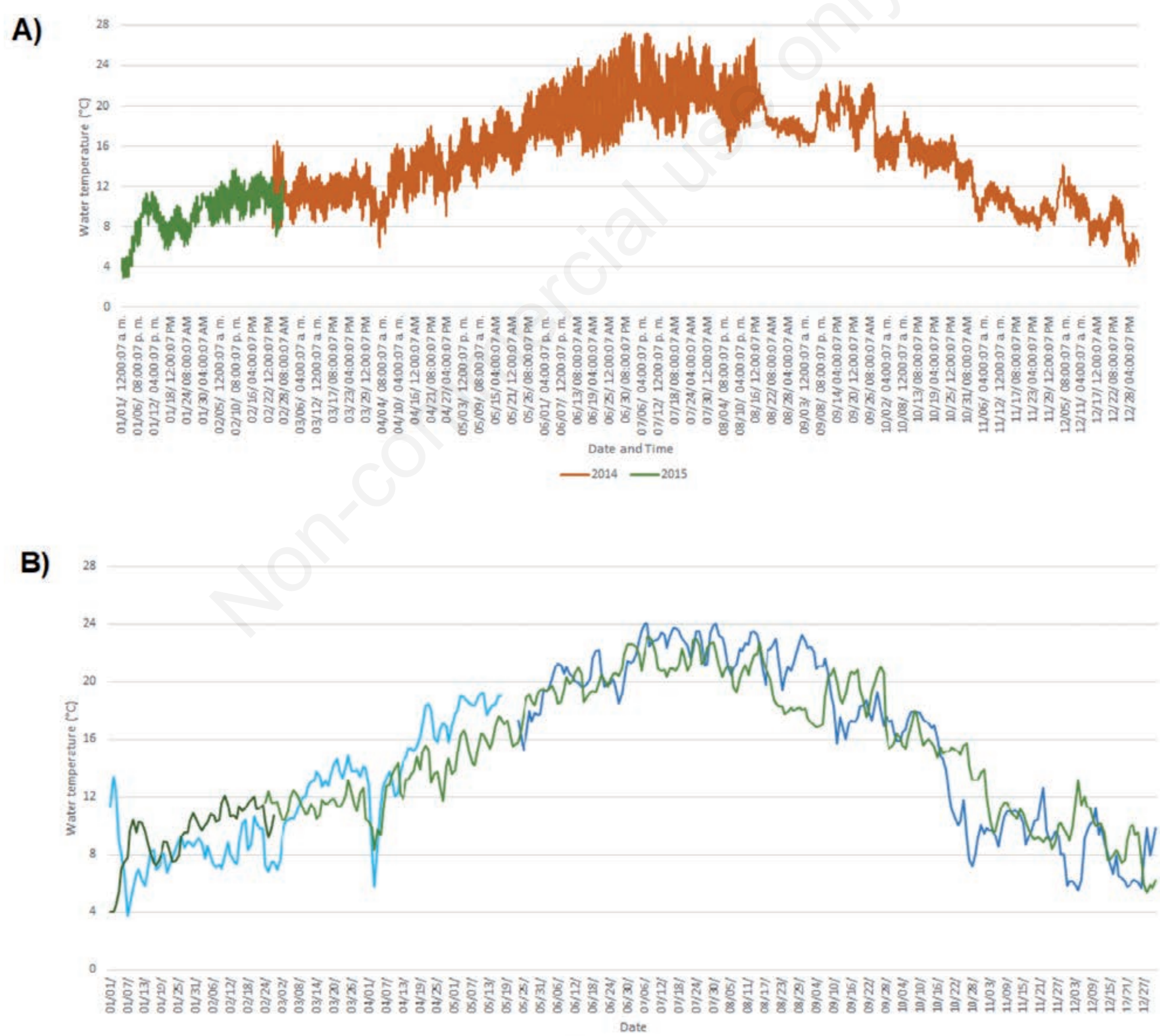

Fig. 3. A) Water temperature recorded with a dual meter at 1-hour intervals, from 2014 to February 2015. B) Daily average temperature from May 1996 to February 2015, at an altitude of 1,220 m asl, in San Rafael Creek, SSPM, Baja California.

accumulated hours with temperatures ≥28°C, giving a total of 1114 between May 3 and September 27. The HadCM3 2050 model with an increase of 0.85°C predicted the lowest number of hours above the 28°C, giving a total of 640 accumulated hours, from May 26 to September 26 (Tab. 1). The highest frequency of ≥28°C events were identified at San Antonio de Murillos Creek, the site with the highest incidence of warm temperatures, mainly due to its lower altitude (553 m asl) than the other two study sites (San Rafael, 1,220 m asl; and La Grulla, 2,080 m asl). The minimum altitude in the SSPM at which daily and hourly average temperature values ≥28°C would not present in the streams subject to the present research was calculated based on the temperature projections described above.

For the year 2025, a daily average temperature lower than 28°C (non-lethal) is predicted to occur at a minimum elevation of 491.04 m asl, by the least extreme model in the present study (HadCM3 R30 2025) (+0.45°C), while 511.32 m asl is the minimum altitude at which average daily temperature values <28°C are predicted to occur by the most extreme model (Mote 2025) (+0.75°C) (Fig. 7A). For the year 2050, average daily temperatures below 28°C are predicted at a minimum elevation of 545.12 m asl by the HadCM3 model (+0.85°C) and at 700.57 m asl by the Mote 2050 model (+2°C) (Fig. 7B).

Hourly temperatures lower than 28°C (non-lethal) are predicted by 2025 at an altitude ranging from 868 (according to HadCM3 2025) to 898 m asl (according to Mote 2025, the most extreme model used in the present study) (Fig. 8A). For the year 2050, hourly temperatures below 28°C are predicted within a range of 908 (HadCM 2050) and 1028 m asl (Mote 2050) (Fig. 8B).

DISCUSSION

In spite of that several studies have projected the effects of increasing temperatures on salmonid distribution considering a broad geographic domain (Nakano *et al.*, 1996; Flebbe *et al.*, 2006; Rieman *et al.*, 2007), our study was done on a regional scale in the western slope of the Sierra San Pedro Mártir (northwestern Mexico) to predict the effects of temperature increases (0.45 to 2.0°C) on the altitudinal distribution of the endemic southern rainbow trout (*O. mykiss nelsoni*) during the years 2025 and 2050.

The lethal water temperature (≥28°C) for southern rainbow trout in North America (Matthews and Berg, 1997; Kammerer and Heppell, 2013b; Nusslé *et al.*, 2015) was recorded in our study region at the San Antonio de Murillos site (553-560 masl), where the endemic trout reaches its lowest limit of altitudinal distribution (Ruiz-Campos, 2017). In this site, a total of 365 hours with temperatures ≥28°C were recorded between 1 June 2014 and 26 September 2014. These temperatures above 28°C significantly exceeded the duration and intensity of those found to be conducive for the survival of native trout in streams of southern California, USA (Nusslé *et al.*, 2015).

Based on the values discussed above, the San Antonio de Murillos site represents the location most vulnerable to global warming and, therefore, that most likely to generate a displacement in the altitudinal distribution of *O. m. nelsoni* trout to colder habitats upstream (see Rieman *et al.*, 2007). Fish exposed to temperatures above this threshold experience physiological cellular stress, including the synthesis of heat shock proteins (HSP) 30 and 70 (Lund *et al.*, 2002), with levels of the latter increasing during acute thermal exposure (Mesa *et al.*, 2002).

A comparison of the water temperatures at the study site with the highest elevation (La Grulla Creek) between June 1999 and May 2000 and August 2015 and April 2019 revealed a greater seasonal variability in daily average temperature intervals, especially in the summer seasons of the second period. This represents a latent threat not only for endemic trout, but also for other aquatic species that inhabit this mountainous ecosystem, thus coinciding with the effects of global warming projected by the IPCC.

Tab. 1. Number of accumulated hours with water temperatures greater than ≥28°C in three sites of the Sierra San Pedro Mártir, Baja California, Mexico, based on projections with three different models for the years 2025 and 2050.

Site	Model	Year 2025		Year 2050	
		Hours ≥28°C	Period	Hours ≥28°C	Period
La Grulla	GFDL R30	0	0	0	0
	HadCM3	0	0	0	0
	Mote	0	0	0	0
San Rafael	GFDL R30	0	0	9	30 June-8 August
	HadCM3	0	0	3	30 June-8 August
	Mote	0	0	53	29 June-15 August
San Antonio de Murillos	GFDL R30	548	26 May-26 September	686	26 May-26 June
	HadCM3	493	31 May-26 June	640	26 May-26 September
	Mote	610	29 June-26 September	1,114	3 May-27 September

It should be noted that the same measurement methodology was used for both aforementioned study periods.

Various climate change scenarios predict an increase in water temperatures, which for the rainbow trout will lead to a higher energy cost if the warmer currents do not produce enough food resources to satisfy its metabolic de-

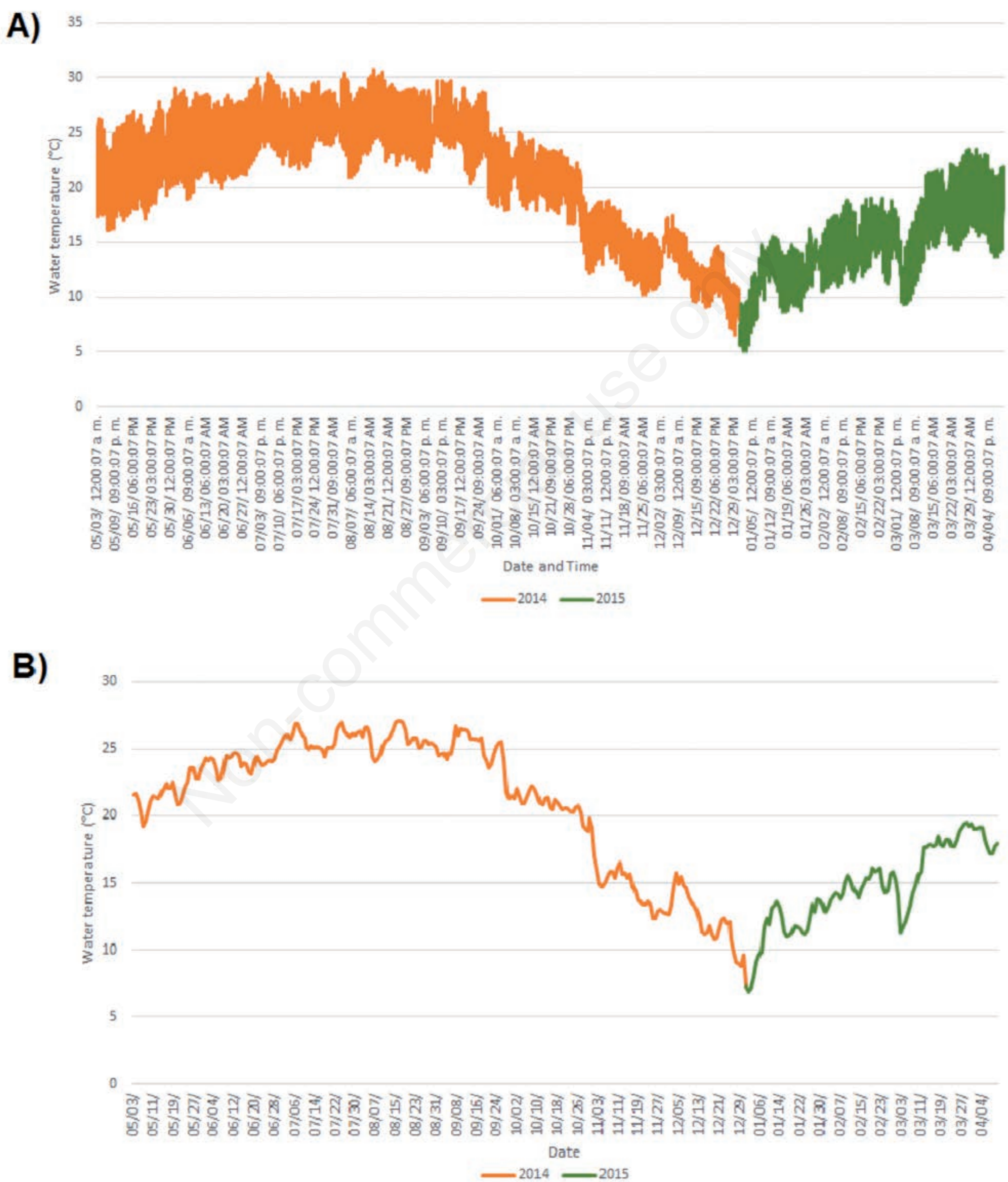

Fig. 4. A) Water temperature recorded with a dual meter at 1-hour intervals from May 2014 to April 2015. B) Average daily temperature from May 2014 to April 2015, at an altitude of 553 m asl, in San Antonio de Murillos Creek, SSPM, Baja California.

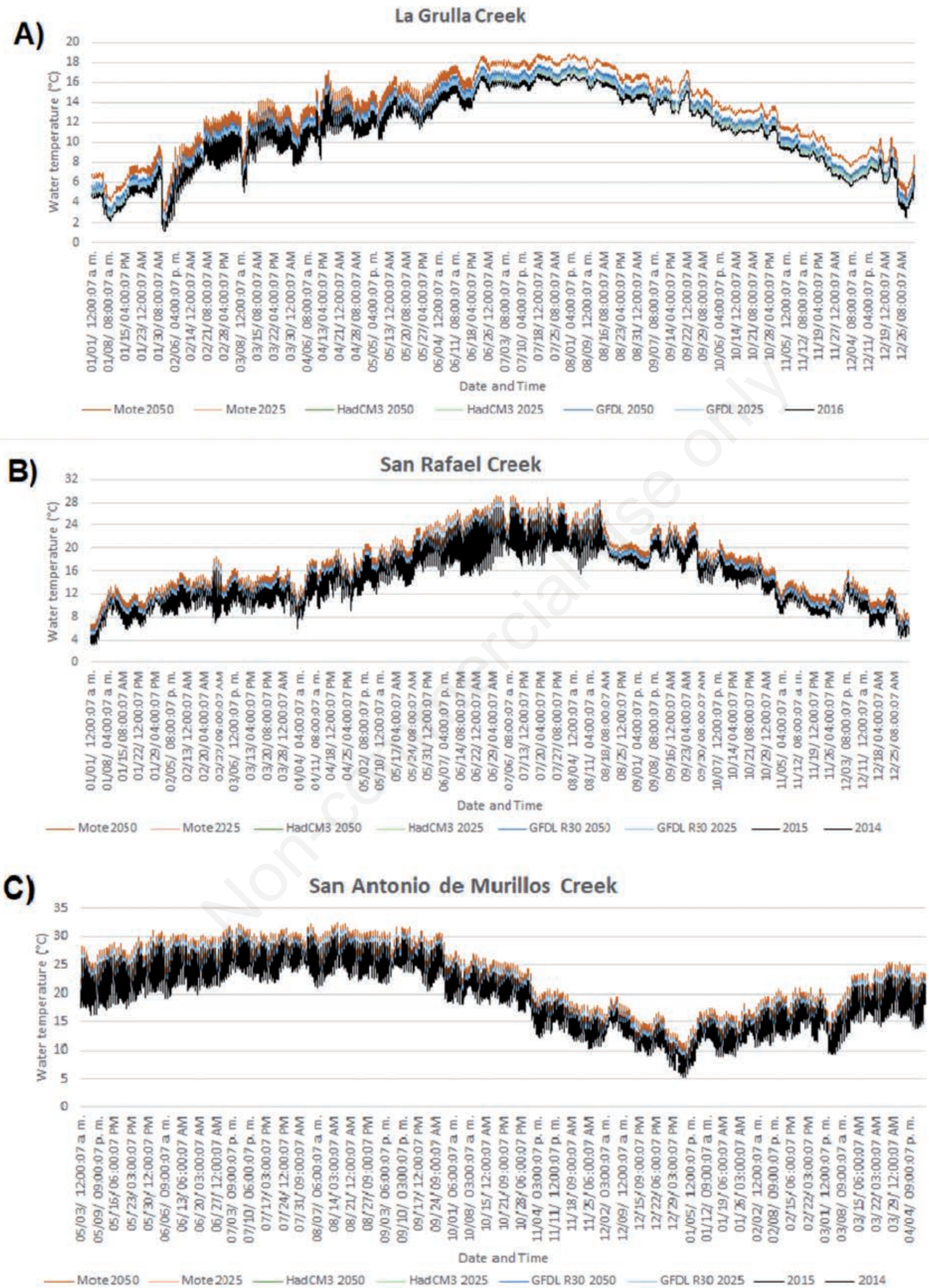

Fig. 5. Temperatures predicted for the years 2025 and 2050 by the climate models GFDL R30, HadCM3, and Mote, for 1-h intervals for La Grulla (A), San Rafael (B), and San Antonio de Murillos (C) creeks, SSPM, Baja California.

mands, leading to reduced levels of growth in individuals (Battin *et al.*, 2007). This increased temperature will produce changes in the distribution of salmonid populations, thus affecting their ability to withstand tropical storms, especially in the summer (Battin *et al.*, 2007). Furthermore, it is likely that summer temperatures will reach or exceed the levels tolerated by trout, causing higher mortality rates (Crozier *et al.*, 2008) and, thus, enabling non-salmonid species, including potential predators or competitors, to flourish in these thermally modified habitats (Reeves *et al.*, 1987). We showed that an increase between 0.45 and 2.0°C, the average water temperature during summer daylight hours at 553 m asl in the type locality of *O. m. nelsoni* (San Antonio de Murillos Creek) may increase the breadth and duration of the lethal temperature range for this subspecies, as occurs in the rainbow trout populations of southern California, USA, at temperatures ≥28°C (Nusslé *et al.*, 2015). Therefore, these temperature changes would generate a confinement in this species' altitude distribution range, wherein it is only able to survive in streams at elevations permitting the appropriate thermal range.

The predicted scenarios for the altitudinal distribution of the trout in the study area based on increases of 0.75°C and 2.0°C in the years 2025 and 2050, respectively, showing in both cases a reduction of its distributional range of 21-23% for 2025 and 23-31% for 2050. This condition will limit its presence in the type locality situated at an elevation of 553 m.

Finally, a strategy for mitigation of the future effects of the increased frequency of lethal summer temperatures on the survival of the endemic trout subspecies in the type locality, might be achieved by means of the conditioning of habitat *via* expanded use of deep pools as thermal refuges for these trout (Matthews and Berg, 1997).

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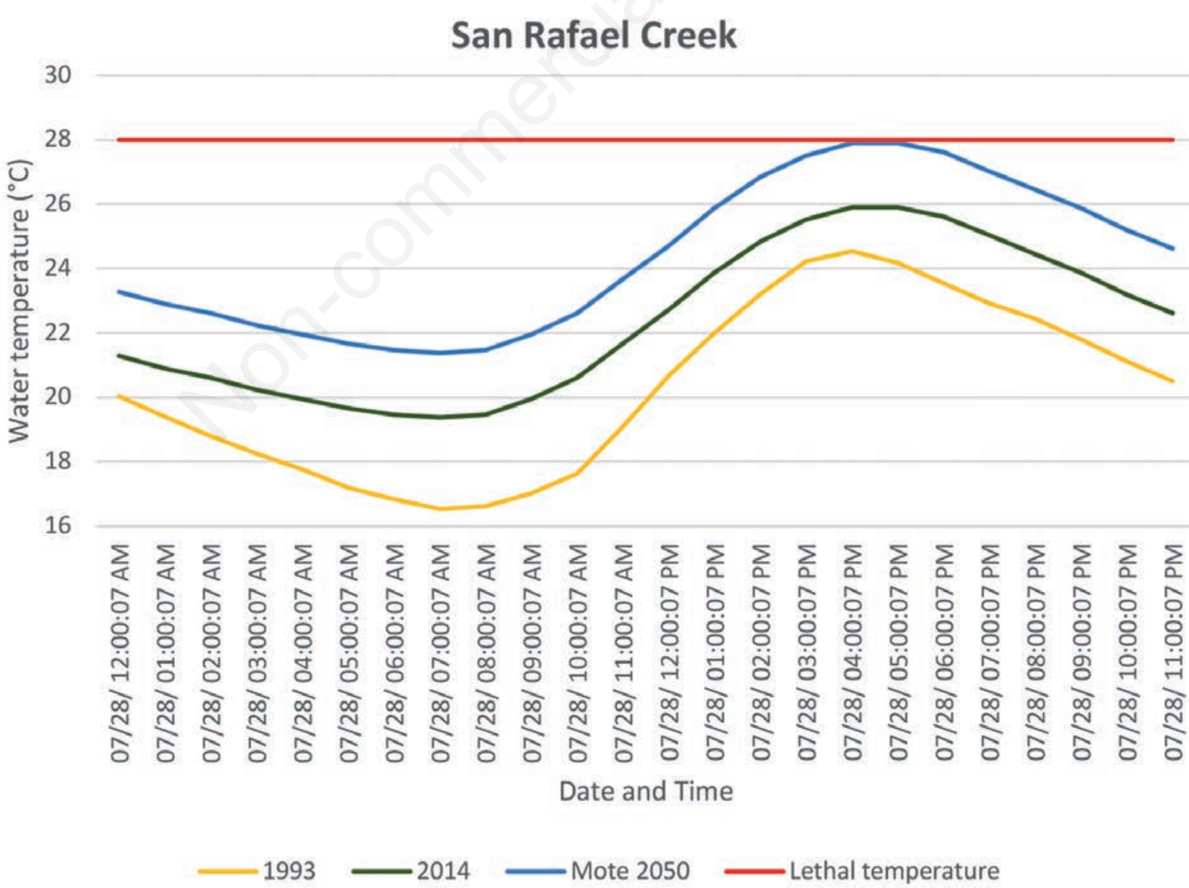

Fig. 6. Water temperatures recorded at 1-hour intervals on 28 July for the years 1993 and 2014, and those projected for the year 2050 with the climate model (Mote) used for San Rafael Creek, SSPM, Baja California.

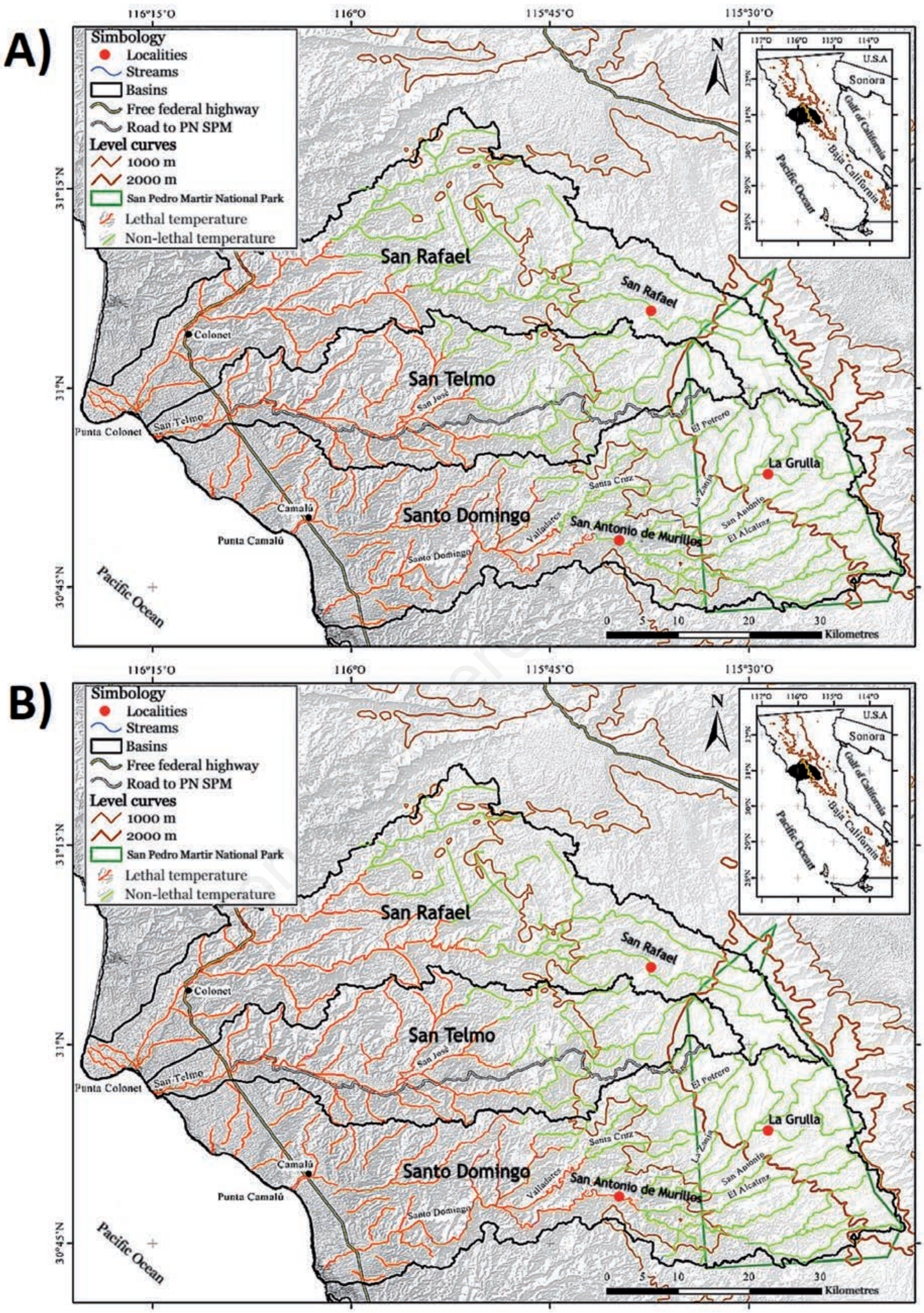

Fig. 7. Minimum altitude with daily average temperature values below 28°C in the Santo Domingo, San Telmo, and San Rafael river basins, as predicted by the Mote model for the years 2025 (A) and 2050 (B).

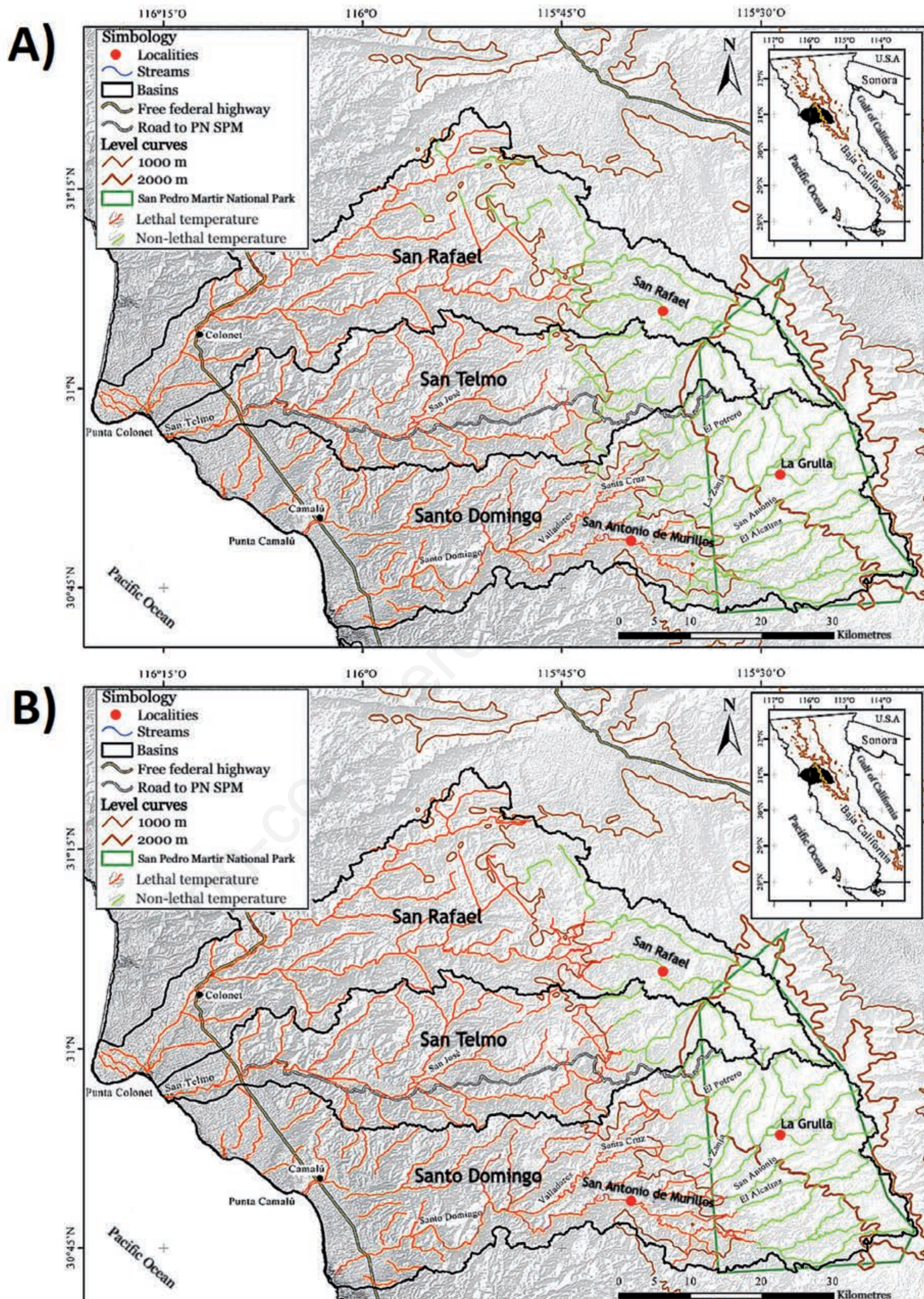

Fig. 8. Minimum altitude with hourly temperature values below 28°C in the Santo Domingo, San Telmo, and San Rafael river basins, as predicted by the Mote model for the years 2025 (A) and 2050 (B).

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